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Effect of plant geometry and nitrogen management through nano urea on growth and productivity of rainfed castor (*Ricinus communis* L)

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Abstract
A field experiment entitled "Effect of Plant Geometry and Nitrogen Management through Nano Urea on Growth and Productivity of Rainfed Castor (*Ricinus communis* L.)" was conducted during *Kharif* 2024 at the School of Agricultural Sciences, Dabok, Udaipur. The experiment was consisted of ten treatment combinations [A. crop geometry (90 cm × 45 cm and 60 cm × 45 cm) and B. nitrogen management {Control, 40, 60 kg N ha^{-1}, 40 kg N ha^{-1} + nano urea (4 ml L^{-1}) and 60 kg N ha^{-1} + nano urea (4 ml L^{-1})}] and these were replicated three times in Factorial Randomized Block Design. The results revealed that wider spacing (90 cm × 45 cm) significantly improved growth attributes such as number of branches $plant^{-1}$ (5.98), dry matter accumulation at harvest (152.48 g $plant^{-1}$), and seed yield (11.40 q ha^{-1}), along with higher net return (₹27,887 ha^{-1}) and B:C ratio (1.76). Among nitrogen treatments, application of 60 kg N ha^{-1} + nano urea (4 ml L^{-1}) recorded the highest values for growth & attributes as well as seed yield (12.57 q ha^{-1}), and economic return (₹32,435 ha^{-1}) with a B:C ratio of 1.85.

Keywords: Castor, nano urea, plant geometry, yield, nitrogen

Introduction
Castor (*Ricinus communis* L.) is a vital non-edible oilseed crop cultivated primarily in arid and semi-arid regions for its high-quality industrial oil. India ranks first in global castor seed production, contributing over 80% of the world's total output, with Gujarat, Rajasthan, Andhra Pradesh and Telangana being the major castor-growing states (Meena *et al*., 2021) [10]. Despite its resilience to drought and low input demand, the productivity of castor under rainfed conditions remains sub-optimal due to poor agronomic practices, particularly inadequate nutrient and plant spacing management (Patel *et al*., 2020) [5].

Plant geometry significantly influences light interception, canopy development, nutrient uptake, and ultimately yield in castor. Wider spacing improves aeration, reduces intra-specific competition, and facilitates better branching and capsule development, while closer spacing may promote early ground cover and reduce soil moisture loss (Ramesh *et al.*, 2017) [6].

Recently, nano urea has emerged as a novel nitrogen fertilizer delivering nutrients in nano-sized particles, enhancing nitrogen use efficiency (NUE), reducing environmental losses, and increasing crop productivity (Singh *et al*., 2023) [11]. Foliar application of nano urea has shown potential to supplement basal nitrogen in a more efficient and economical manner, especially under moisture-limited conditions (Kumar & Yadav, 2022) [2].

Integrating optimum plant geometry with nitrogen management through nano urea could offer a synergistic strategy to improve growth, yield attributes, and economic returns of castor under rainfed agro-ecosystems. However, research on this integrated approach remains limited, particularly in the semi-arid regions of Rajasthan. Therefore, the present investigation was undertaken to assess the effect of plant geometry and nitrogen management through nano urea supplementation.

Materials and methods
A field experiment entitled "Effect of Plant Geometry and Nitrogen Management through Nano Urea on Growth and Productivity of Rainfed Castor (*Ricinus communis* L.)" was carried out during the *kharif* 2024 at the School of Agricultural Sciences, Dabok, Udaipur

(Rajasthan). The site is geographically located at 24°37′ N latitude, 73°53′ E longitude, and 513.0 m above mean sea level. It falls under Agro-climatic Zone IVa (Sub-Humid Southern Plains and Aravalli Hills) of Rajasthan.

The experimental soil was clay loam, with a pH of 7.21 and electrical conductivity of 0.89 dS m^{-1}. It was low in available nitrogen (250.3 kg ha^{-1}), medium in available phosphorus (20.3 kg ha^{-1}), and potassium (349.3 kg ha^{-1}).

The experiment was laid out in a Factorial Randomized Block Design (FRBD) consisted of ten treatment combinations [A. crop geometry (90 cm × 45 cm and 60 cm × 45 cm) and B. nitrogen management {Control, 40, 60 kg N ha^{-1}, 40 kg N ha^{-1} + nano urea (4 ml L^{-1}) and 60 kg N ha^{-1} + nano urea (4 ml L^{-1}).

The castor hybrid variety ICH-5, developed by ICAR-IIOPR, Hyderabad, was used as the test crop. The crop was sown on 2nd August 2024 using a seed rate of 10-15 kg ha^{-1} depending on spacing. A basal dose of phosphorus @ 40 kg P_2O_5 ha^{-1} was applied uniformly through single super phosphate. Nitrogen was applied in two equal splits: half at sowing and half at 30 DAS through urea as per treatment.

The data recorded for evaluation of treatment were requested to statistically analysis by techniques of analysis of variance as advocated by Fisher, (1925). The pooled analysis of the data was also carried out to estimate the trend of treatments applied.

Results and Discussion

Effect of Plant Geometry

Plant geometry had a significant influence on most growth parameters, yield attributes, and economics of castor. Wider spacing (90 cm × 45 cm) recorded significantly lower plant population (24,244 ha^{-1}) than 60 cm × 45 cm (36,724 ha^{-1}) due to reduced plant density. However, the wider spacing produced significantly higher number of branches $plant^{-1}$ (5.98), functional leaves $plant^{-1}$ and dry matter accumulation (152.48 g $plant^{-1}$ at harvest), indicating better resource utilization per plant owing to less competition for nutrients, light, and moisture. The superiority of wider spacing was also reflected in plant height, which remained slightly lower under 90 cm spacing at early stages but became comparable to 60 cm spacing at harvest (136.90 cm vs 151.16 cm), owing to better branching and sturdy growth habit. A similar trend was observed by Patel *et al.* (2023) [4] and Reddy *et al.* (2021) [8], They reported that wider spacing in castor enhanced branching and biomass accumulation due to improved aeration and photosynthetic efficiency.

Significantly higher seed yield (11.40 q ha^{-1}), number of spikes $plant^{-1}$ (4.79), capsules $plant^{-1}$ (188.18) and seed yield $plant^{-1}$ (179.89 g) were recorded under 90 cm × 45 cm geometry. Biological yield was also higher under wider spacing (37.12 q ha^{-1}), the harvest index was comparatively lower (47.26%) than the narrower spacing (50.96%), indicating more vegetative biomass production. Although closer spacing increased plant population per unit area, competition among plants may have suppressed individual yield components, thereby reducing per plant productivity (Meena *et al*., 2020) [3]. However, seed yield per hectare was slightly higher in wider spacing (11.40 q ha^{-1}) compared to 10.68 q ha^{-1} in narrow spacing, though the difference was statistically significant.

Economically, wider spacing (90 cm × 45 cm) yielded a significantly higher net return (₹ 27,887 ha^{-1}) and B:C ratio (1.76) than 60 cm × 45 cm. This may be attributed to better yield performance $plant^{-1}$, despite the lower number of plants $hectare^{-1}$. These findings corroborate with those of Reddy *et al*. (2022) [7], who reported increased profitability in castor with optimal spacing that allows better canopy development and spike formation.

Effect of Nitrogen Management through Nano Urea

Nitrogen management practices significantly influenced growth, yield parameters, yield and economic returns of castor. The treatment comprising 60 kg N ha^{-1} + nano urea @ 4 ml L^{-1} performed superiorly across all parameters.

Application of 60 kg N ha^{-1} + nano urea @ 4 ml L^{-1} resulted in significantly higher plant height (159.48 cm at harvest), branches $plant^{-1}$ (6.20), functional leaves (56.06), and dry matter accumulation at haevest (161.70 g $plant^{-1}$), reflecting the importance of sufficient nitrogen availability for sustained vegetative growth. This could be attributed to better nitrogen absorption and translocation facilitated by nano urea, which improves nitrogen use efficiency due to its higher surface area and targeted delivery (Sankaran *et al*., 2023) [9]. The improvement in growth traits with nitrogen application may be due to increased chlorophyll synthesis, enhanced photosynthesis, and improved root activity (Kumar *et al*., 2022) [2]. Foliar application of nano urea provided rapid nitrogen absorption and reduced losses compared to granular urea, leading to better nitrogen-use efficiency.

Yield attributes such as number of spikes $plant^{-1}$ (4.99), capsules $plant^{-1}$ (195.63), and 100-seed weight (26.71 g) were significantly higher in N_5 @ 4 ml L^{-1} treatment. Seed yield (12.57 q ha^{-1}) and biological yield (42.31 q ha^{-1}) were maximum in 60 kg N ha^{-1} + nano urea @ 4 ml L^{-1}, surpassing conventional N levels. However, harvest index (42.48%) remained statistically at par with other N treatments, suggesting balanced partitioning between seed and stalk. The improvement in yield is attributed to enhanced source-sink relationship and better partitioning of photosynthates under sufficient nitrogen supply (Sharma *et al*., 2021) [10].

Notably, nano urea supplementation with 40 or 60 kg N ha^{-1} was more effective than sole application of 60 kg N ha^{-1}, indicating synergistic benefits of foliar nano urea. This supports findings by Singh *et al.* (2023) [11], who reported 10-15% higher yield in oilseed crops with nano urea integration compared to conventional urea alone.

The significantly higher net return (₹ 32,435 ha^{-1}) and B:C ratio (1.85) obtained under 60 kg N ha^{-1} + nano urea @ 4 ml L^{-1} treatment can be ascribed to the improved yield with marginal cost increase due to nano urea application. Similar economic advantages of nano urea in oilseed crops were also reported by Verma *et al.* (2024) [12], highlighting its role in cost-effective and sustainable nitrogen supplementation. In contrast, the control recorded the lowest net return (₹5,930 ha^{-1}). Increased returns under nano urea treatments were due to better yield performance and efficient nitrogen utilization, outweighing the cost of nano urea application.

Table 1: Effect of plant geometry and nitrogen management on plant population and branches plant^{-1} of castor

Treatments	Plant population (ha^{-1})		Branches plant^{-1}		
	20 DAS	Harvest	90 DAS	120 DAS	Harvest
Crop geometry					
90 cm × 45 cm	24625	24244	4.45	5.68	5.98
60 cm × 45 cm	37136	36724	3.82	4.87	5.14
SEm±	889	928	0.11	0.13	0.19
CD (P=0.05)	2641	2757	0.33	0.37	0.56
Nitrogen management					
Control	29938	29658	3.51	4.40	4.72
40 kg N ha^{-1}	29901	29521	3.98	5.10	5.33
60 kg N ha^{-1}	31542	30995	4.25	5.44	5.71
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	31310	30916	4.35	5.56	5.83
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	31711	31330	4.59	5.86	6.20
SEm±	562	587	0.07	0.08	0.12
CD (P=0.05)	NS	NS	0.21	0.24	0.35

Table 2: Effect of plant geometry and nitrogen management on plant height and functional leaves of castor

Treatments	Plant height (cm)					Number of functional leaves plant^{-1}				
	30 DAS	60 DAS	90 DAS	120 DAS	Harvest	30 DAS	60 DAS	90 DAS	120 DAS	Harvest
Crop geometry										
90 cm × 45 cm	12.11	39.09	117.14	122.33	136.90	5.54	19.79	32.88	53.42	13.37
60 cm × 45 cm	14.73	43.16	129.31	135.31	151.16	4.97	17.88	29.70	48.29	12.88
SEm±	0.38	1.24	3.15	4.10	4.73	0.13	0.41	0.69	1.32	0.33
CD (P=0.05)	1.12	3.69	9.36	12.19	14.04	0.37	1.23	2.05	3.93	NS
Nitrogen management										
Control	13.01	35.12	105.06	108.91	121.70	4.40	16.07	26.59	43.40	12.55
40 kg N ha^{-1}	13.01	39.85	119.41	124.07	139.54	5.10	18.28	30.44	49.35	12.94
60 kg N ha^{-1}	13.70	42.12	126.25	131.92	148.88	5.42	19.27	32.23	52.04	13.01
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	13.60	43.08	129.12	135.03	150.54	5.55	19.79	32.85	53.42	13.36
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	13.78	45.46	136.30	144.17	159.48	5.82	20.76	34.33	56.06	13.77
SEm±	0.24	0.78	1.99	2.60	2.99	0.08	0.26	0.44	0.84	0.21
CD (P =0.05)	NS	2.33	5.92	7.71	8.88	0.24	0.78	1.30	2.49	NS

Table 3: Effect of plant geometry and nitrogen management on dry matter accumulation of castor

Treatments	Dry matter accumulation (g plant^{-1})				
	30 DAS	60 DAS	90 DAS	120 DAS	Harvest
Crop geometry					
90 cm × 45 cm	12.37	55.72	115.35	147.55	152.48
60 cm × 45 cm	11.88	50.38	104.49	133.70	138.30
SEm±	0.34	1.56	3.61	4.90	4.64
CD (P=0.05))	NS	4.62	10.72	14.57	13.79
Nitrogen management					
Control	11.55	45.14	94.01	118.15	122.32
40 kg N ha^{-1}	11.94	51.32	105.58	135.35	140.35
60 kg N ha^{-1}	12.01	54.32	112.68	145.15	149.65
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	12.36	55.76	115.25	147.60	152.93
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	12.77	58.71	122.08	156.87	161.70
SEm±	0.21	0.98	2.28	3.10	2.94
CD (P=0.05))	NS	2.92	6.78	9.22	8.72

Table 4: Effect of plant geometry and nitrogen management on seed attributes of castor

Treatments	Yield attributes				
	Seed yield plant^{-1} (kg)	Number of spike plant^{-1}	Number of capsules plant^{-1}	Spike length (cm)	100 seed weight (g)
Crop geometry					
90 cm × 45 cm	179.89	4.79	188.18	23.18	25.18
60 cm × 45 cm	161.28	4.35	171.35	22.49	24.49
SEm±	4.26	0.13	5.08	0.58	0.58
CD (P=0.05))	12.66	0.40	15.08	NS	NS
Nitrogen management					
Control	72.38	3.96	156.53	20.36	22.36
40 kg N ha^{-1}	179.76	4.52	177.78	22.40	24.40
60 kg N ha^{-1}	195.27	4.66	183.22	23.17	25.17
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	198.10	4.73	185.68	23.53	25.53
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	207.42	4.99	195.63	24.71	26.71
SEm±	2.69	0.08	3.21	0.37	0.37
CD (P=0.05)	8.01	0.25	9.54	1.09	1.09

Table 5: Effect of plant geometry and nitrogen management on seed yield of castor

Treatments	Yield (q ha^{-1})			Harvest index (%)
	Seed	Stalk	Biological	
Crop geometry				
90 cm × 45 cm	11.40	25.72	37.12	47.26
60 cm × 45 cm	10.68	23.47	34.15	50.96
SEm±	0.25	0.63	0.72	1.97
CD (P=0.05)	0.74	1.88	2.15	NS
Nitrogen management				
Control	7.16	9.79	16.96	75.40
40 kg N ha^{-1}	11.27	26.40	37.67	42.74
60 kg N ha^{-1}	12.12	28.59	40.71	42.41
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	12.07	28.47	40.54	42.52
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	12.57	29.74	42.31	42.48
SEm±	0.16	0.40	0.46	1.25
CD (P=0.05)	0.46	1.19	1.36	3.70

Table 6: Effect of plant geometry and nitrogen management on economics

Treatments	Net return (₹ ha^{-1})	B:C ratio
Crop geometry		
90 cm × 45 cm	27887	1.76
60 cm × 45 cm	22878	1.61
SEm±	1377	0.04
CD (P=0.05)	4091	0.11
Nitrogen management		
Control	5930	1.17
40 kg N ha^{-1}	27089	1.75
60 kg N ha^{-1}	31552	1.87
40 kg N ha^{-1} + nano urea (4 ml L^{-1})	29905	1.79
60 kg N ha^{-1} + nano urea (4 ml L^{-1})	32435	1.85
SEm±	871	0.02
CD (P=0.05)	2588	0.07

Conclusion

Among the geometrical arrangements, 90 cm × 45 cm spacing proved superior in terms of growth, yield attributes, seed yield (11.40 q ha^{-1}), and net return (₹27,887 ha^{-1}) compared to the closer spacing of 60 cm × 45 cm. Regarding nitrogen management, application of 60 kg N ha^{-1} + nano urea @ 4 ml L^{-1} emerged as the most effective treatment. It recorded the highest seed yield (12.57 q ha^{-1}), and net return (₹32,435 ha^{-1}) with a B:C ratio of 1.85, indicating superior nitrogen use efficiency and economic profitability.

Thus, for enhancing growth, productivity, and profitability of castor under rainfed conditions of southern Rajasthan, the combination of 90 cm × 45 cm spacing and 60 kg N ha^{-1} + foliar spray of nano urea @ 4 ml L^{-1} at 30 DAS is recommended as an effective and sustainable agronomic practice.

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